Fermilab

Particle Physics Division
Mechanical Department Engineering Note

Number: MD-ENG-305 Date: 7 JAN 2011

Project Internal Reference:

Project: NOvA

Title: NOvA PVC Plane Extrusion Lifting Fixture

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Reviewer(s):

Key Words: NOvA, Below-the-hook lifting device

Abstract Summary: The following engineering note provides the calculations of stresses and compares these to the allowable values for a lifting fixture that is to be used to lift PVC extrusions for the NOvA project.

Applicable Codes: ASME B30.20

5022TA

BELOW-THE-HOOK LIFTING DEVICE
Engineering Note Cover Page

Lifting Device Numbers:

FNAL Site No/ ________________ Div. Specific No. ________________ Asset No. ________________

If applicable If applicable If applicable

ASME B30.20 Group: (check one)

[X] Group I Structural and Mechanical Lifting Devices
[ ] Group II Vacuum Lifting Devices
[ ] Group III Magnets, Close Proximity Operated
[ ] Group IV Magnets, Remote Operated

Device Name or Description: Unistrut fixture for lifting PVC plane extrusions

Device was (check all applicable)

[ ] Purchased from a Commercial Lifting Device Manufacturer. Mfg Name ________________
[X] Designed and Built at Fermilab
[ ] Designed by Fermilab and Built by a Vendor. Assy drawing number ________________
[ ] Provided by a User or other Laboratory
[ ] Other: Describe ________________

Engineering Note Prepared by KYLE BECZKIEWICZ Date 7 JAN 2011

Engineering Note Reviewed by ________________ Date ________________

Lifting Device Data:

Capacity 200 pounds

Fixture Weight 146 pounds

Service: [X] normal [ ] heavy [ ] severe
(refer to B30.20 for definitions)

Duty Cycle _______ 8, 16 or 24 hour rating (applicable to groups III, and IV)

Inspections Frequency ________________

Rated Load Test by FNAL (if applicable) Date ________________ Load ________________

[ ] Check if Load Test was by Vendor and attach the certificate

Satisfactory Load Test Witnessed by: ________________

Signature (of Load Test Witness) ________________

Notes or Special Information:

The lifting fixture described in this note is built for lifting PVC plane extrusions for the NOvA project. The main purpose of the fixture is to aid in the lifting so that the task can be more easily accomplished than if it were to be done by hand.

Background

The lifting fixture described in this engineering note consists of several pieces of Unistrut bolted together to make a rectangular frame (dark green pieces in Fig. 2 below), which is used to lift 162" x 52" PVC planes, which weigh approximately 200 lbs.

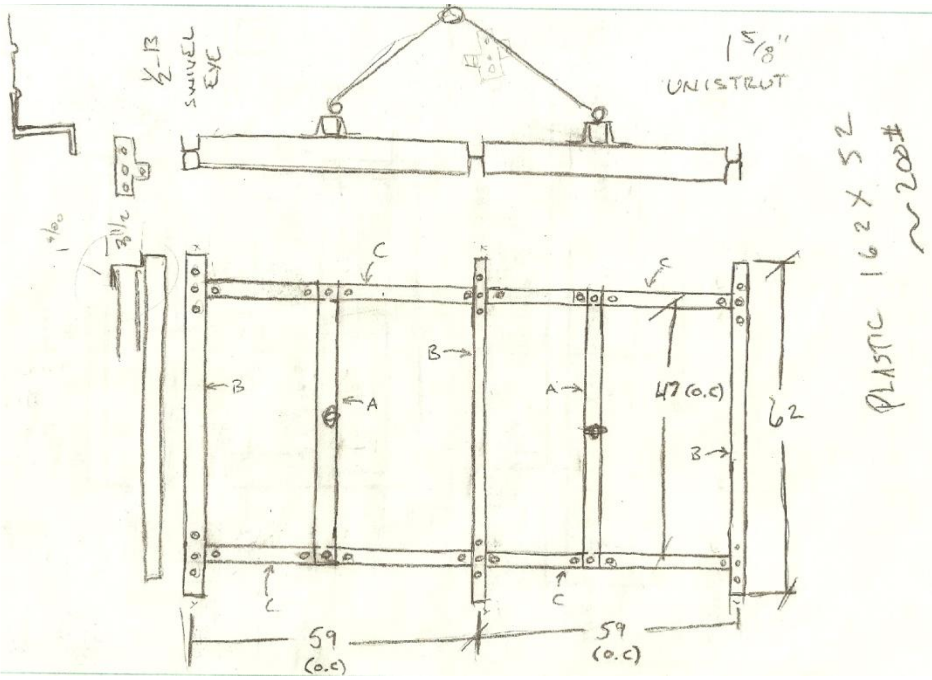


Figure 1: Drawing of lifting fixture

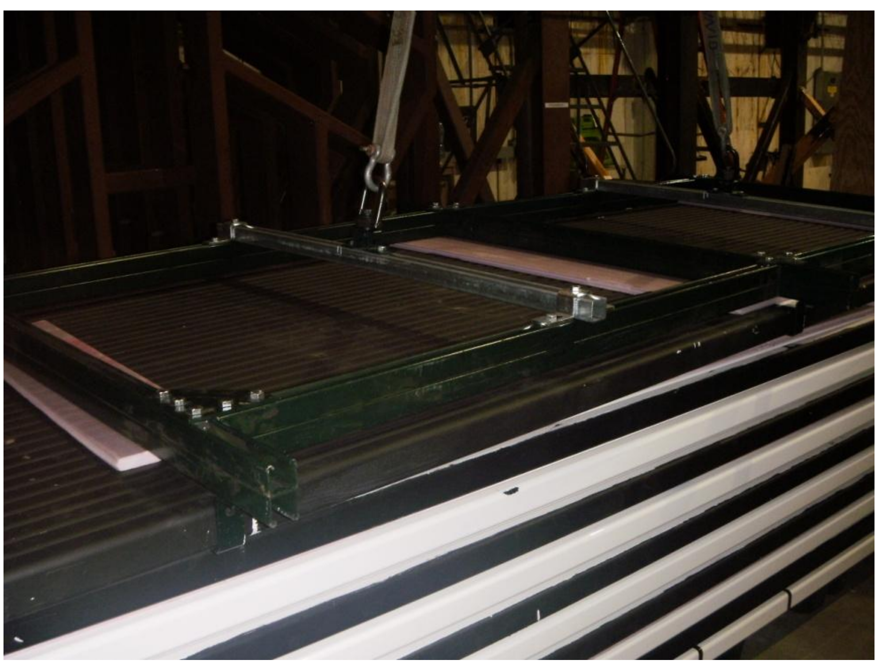


Figure 2: Lifting Fixture

The lifting fixture has two lift points, with a ½”-13 swivel eye hoist ring at each point. The work load limit for each hoist ring is 2500 lbs, well above the weight that is to be lifted.

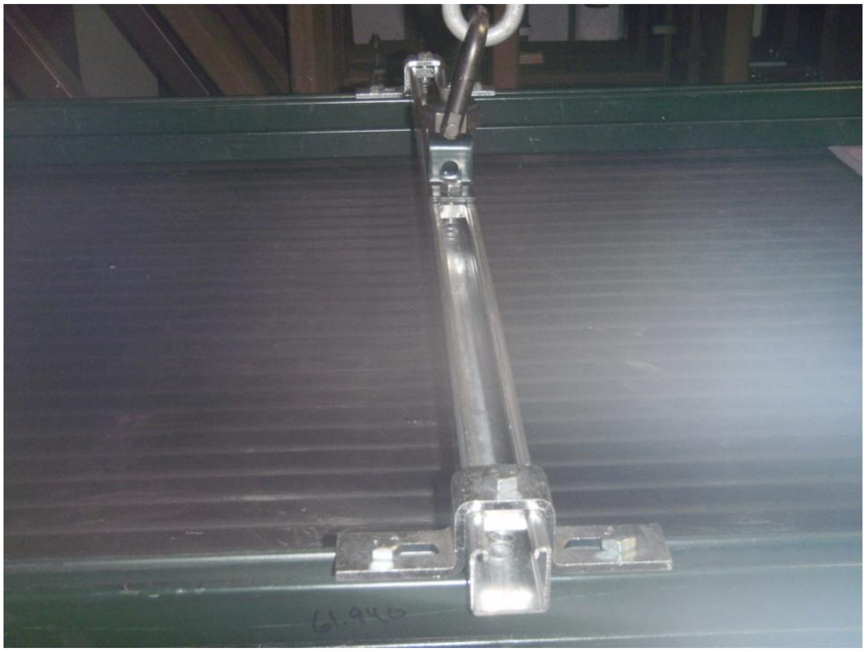


Figure 3: ½”-13 Hoist Ring attachment

The plastic is held at 6 different places on the lifting fixture using z-brackets, which can be seen in the picture below.

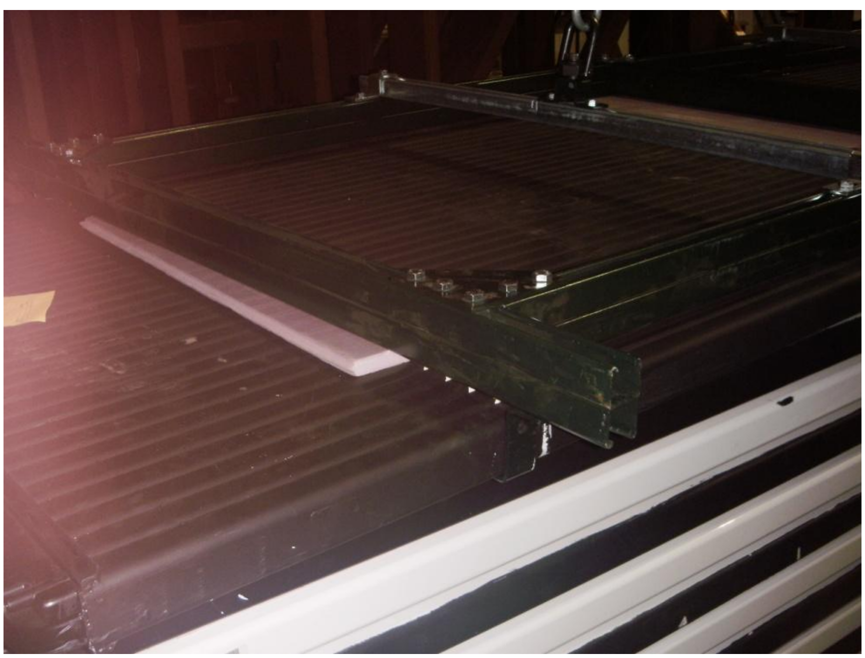


Figure 4: Z-bracket

Analysis

According to ASME B30.20, load-bearing components should be designed to withstand stresses imposed by the combination of the rated load and weight of the lifting fixture, with a minimum design factor of three, based on the material's yield strength. Unistrut, which is made from A1011 SS GR. 33, has a yield strength of 33 ksi. Therefore, the maximum allowable stress in Unistrut would be 11 ksi.

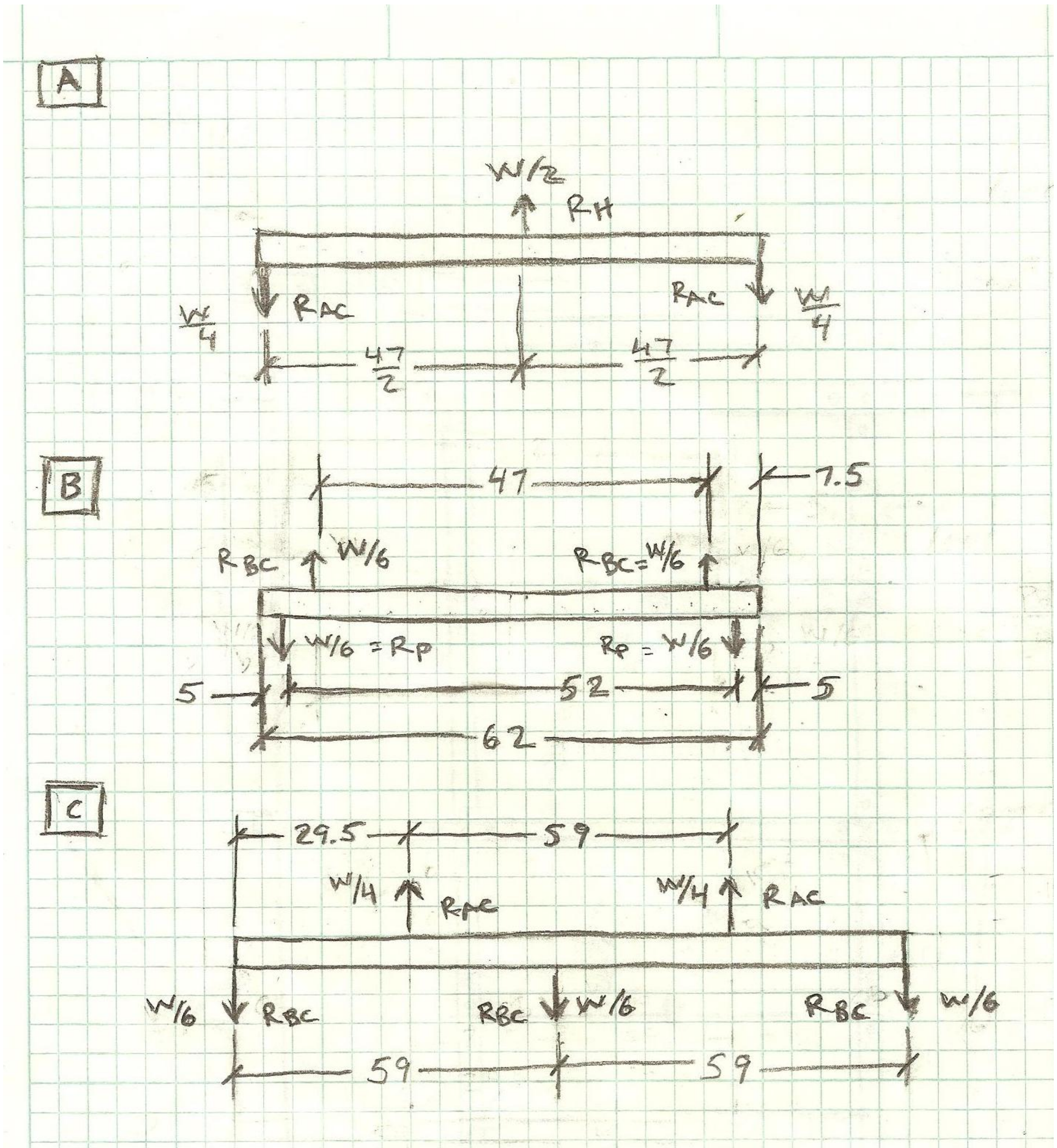


Figure 5: Free-body diagrams of each member

Table 1: Weight, Moments and Stresses in the Lifting Fixture

WEIGHT OF PLASTIC (lbs)	200		
	MEMBER A	MEMBER B	MEMBER C
LENGTH (in)	48.63	62	57.38
NUMBER	2	3	4
TOTAL LENGTH (in)	97.3	186	229.5
WEIGHT PER FT (lbs)	1.89	3.78	3.78
TOTAL WEIGHT (lbs)	15.3	58.6	72.3
FIXTURE WEIGHT (lbs)			146.2
COMBINED WEIGHT (lbs)			346.2
EFFECTIVE LENGTH (in)	47	52	118
MOMENT OF INTERIA (in^4)	0.185	0.928	0.928
MOD OF ELAS. (psi)	2.90E+07	2.90E+07	2.90E+07
a (in.)	N/A	2.50	N/A
MAX DEF. (in.)	0.070	0.002	0.0087
MAX. MOMENT (lbs-in.)	2034	144	1702
ALLOWABLE MOMENT (lbs-in)	5070	14360	14360
SECTION MODULUS (in^3)	0.202	0.571	0.571
BENDING STRESS (ksi)	10.1	0.253	2.54
	OK	OK	OK

The values for weight per foot, moment of inertia, allowable moment and section modulus were all taken from the Unistrut product catalog.

The effective length was used in the calculation of the maximum deflection and maximum moment of the beam. A table with various common beam loadings and their deflections and slopes was used for the calculation of maximum deflection, maximum moment and bending stress.

Calculations

MEMBER A: Simply-supported beam w/ concentrated load at center

- δ_{MAX} = Maximum deflection
- P = combined weight / 2
- L = effective length
- E = modulus of elasticity (assumed)
- I = moment of inertia (given)
- $M_{MAX, A}$ = maximum moment present
- S = section modulus (given)
- σ_{MAX} = maximum bending stress

$$\delta_{MAX,A} = \frac{PL^3}{48EI}$$

$$M_{MAX,A} = \frac{PL}{4}$$

$$\sigma_{MAX,A} = \frac{M_{MAX,A}}{S}$$

MEMBER B: Simply-supported beam w/ two equal, concentrated loads symmetrically placed

- δ_{MAX} = Maximum Deflection
- P = combined weight / 6
- L = effective length
- a = distance from edge support to point acted on by force
- E = Modulus of elasticity (assumed)
- I = moment of inertia (given)
- $M_{MAX, B}$ = maximum moment present
- S = section modulus
- σ_{MAX} = maximum bending stress

$$\delta_{MAX,B} = \frac{Pa}{24EI}(3L^3 - 4a^3)$$

$$M_{MAX,B} = Pa$$

$$\sigma_{MAX,B} = \frac{M_{MAX,B}}{S}$$

Member C was assumed to act as one continuous beam, and was analyzed based on this assumption. The maximum moment in member C was determined using a shear/moment diagram (below), due to the fact that the type of loading present in this beam is not as commonly found as the previous two.

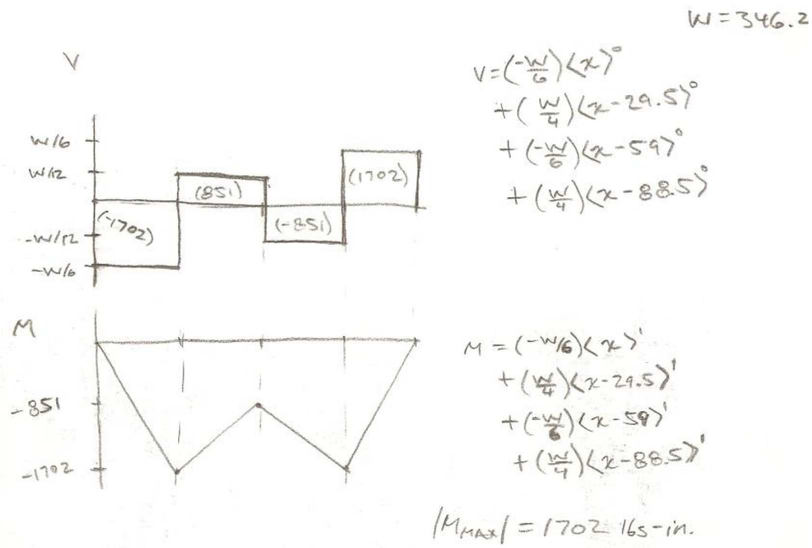


Figure 6: Shear/Moment diagram

The finite element analysis software, I-DEAS, was used to determine the stress and deflection in member C. Half of the beam was modeled and boundary constraints were added to simulate the symmetry of the beam. The values that were determined can be found in the table above.

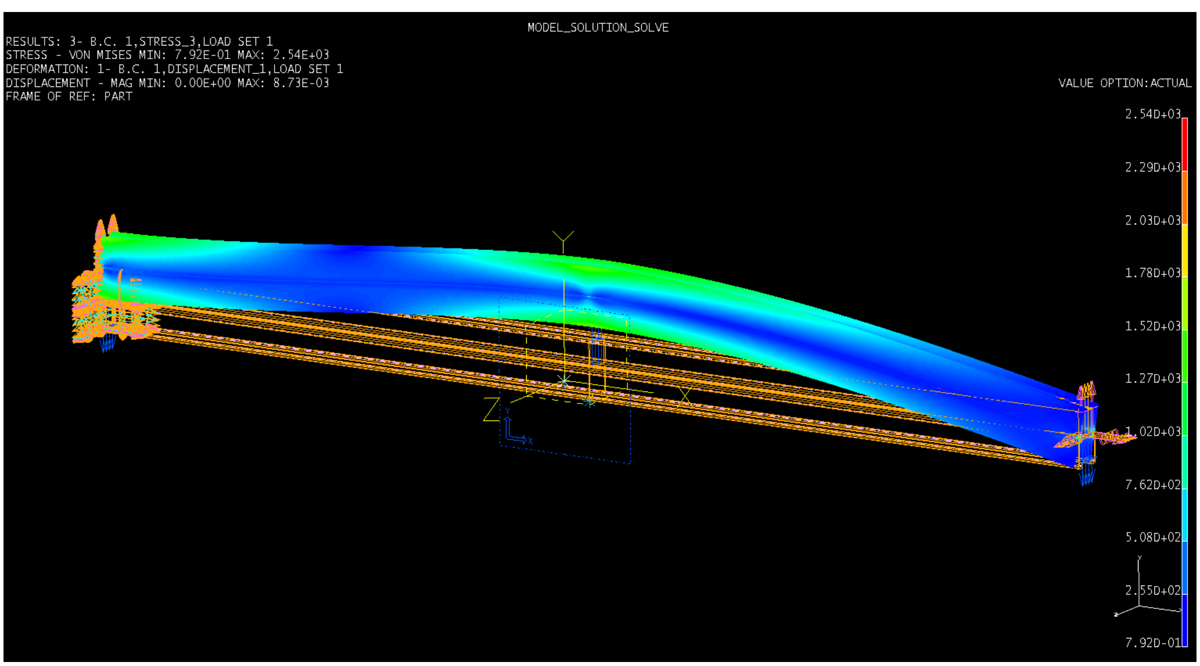


Figure 7: 3-d model of stress and deflection in member C

The maximum bending moment and stresses in each of the three pieces fall within the allowable values set by Unistrut and those established in AMSE B30.20.

The next part of the analysis of the lifting fixture involves determining whether or not the connections are able to withstand the forces that would be applied.There were four main reaction points that involve components in tension:

- the bolts from the hoist ring and U-bracket
- the bolts where member A is attached to member C using a U-bracket
- the bolts where member B is attached to C, using a webbed L-bracket
- the bolts holding the Z-bracket (and plastic) to the bottom of member B

$$\sigma_T = \frac{F}{A}$$

Table 2: Tensile stresses at various points

TENSILE STRESS AT REACTION POINTS				
POINT	H	AC	BC	P
MEMBER ACTED ON	BOLT	BOLT	BOLT	BOLT
DIAMETER (in)	0.5	0.5	0.5	0.5
AREA (in^2)	0.196	0.196	0.196	0.196
#	3	2	3	1
TOTAL AREA ACTED ON (in)^2	0.589	0.393	0.589	0.196
FORCE AT POINT (lbs)	173.1	86.55	57.70	57.70
TENSILE STRESS (ksi)	0.294	0.220	0.098	0.294
	OK	OK	OK	OK

Point H (hoist ring) - the hoist ring is attached to a U-bracket (attached to member A) using ½”-13 bolts. The load from the weight of the fixture and the plastic is assumed to be evenly distributed between the two hoist rings on the fixture. This weight is applied on the area of all three bolts. The tensile stress (0.294 ksi) is below the allowable value of $1/3*F_y$ (15 ksi).

Point AC - each end of member A is attached to member C using a U-bracket that is bolted into member C using two ½”-13 bolts. Therefore, the load is acts on these two bolts, effectively doubling the area on which the force acts. The force acting on the two bolts is one-half of the force acting at the hoist ring, or one-quarter of the total weight of the fixture and plastic. The tensile stress (0.220 ksi) in these bolts is also below the maximum allowable value.

Point BC – the end of member C is bolted to member B at each end using a webbed L bracket (seen in Figs. 2, 4). The force is assumed to be acting on the three bolts attached to member B. The weight acting on these three bolts is one-sixth of the total weight. It can be seen in the table above that the tensile stress (0.098 ksi) is also below the maximum allowable value for A307 bolts.

Point P – the PVC plane extrusions are held using Z-brackets that are bolted to the bottom edge of member B. Each Z-bracket is attached using one ½"-13 bolt. The force acting on the bolt is one-sixth of the total weight. The resulting tensile stress (0.294 ksi) is below the maximum allowable.

The shear stress that occurs in various parts of the lifting fixture was also calculated. There were five areas where the shear stress was calculated in order to make sure that it remained within allowable limits. The five points are as follows:

- Shear in the bolt of the hoist ring
- Shear in the U-bracket holding the hoist ring, attached to member A
- Shear in the U-bracket connecting A to C
- Shear in the webbed L-bracket connecting members B and C
- Shear in the Z-bracket holding the PVC planes

Table 3: Shear stress at various points

POINT	H	H	AC	BC	P
MEMBER ACTED ON	BOLT	U-BRACKET	U-BRACKET	WEBBED L	Z-BRACKET
AREA	0.1963	0.0625	0.4063	1.3438	0.4063
FORCE AT POINT	173.1	173.1	86.55	57.70	57.70
SHEAR STRESS (ksi)	0.882	2.77	0.213	0.0429	0.142
	OK	OK	OK	OK	OK

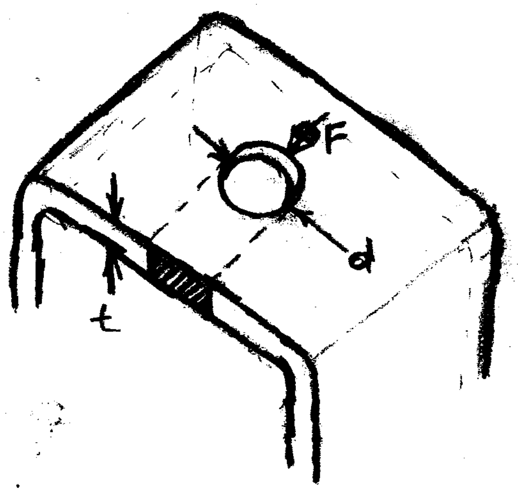
Point H (hoist ring and U-bracket) – At this point, the force taken to be acting on the two pieces is equal to half of the weight of the lifting fixture and PVC extrusion. Due to the fact that, while in use, not all of this weight is acting on the bolt and bracket in shear, the value that is determined for shear stress is a conservative value. Both values (0.882 ksi acting on the bolt, 2.77 ksi acting on the bracket) are still within the range of allowable values.

Point A/C (U-bracket) –the most likely planes of stress that would occur would be through the thickness of the U-bracket as a result of member A being pulled vertically. The value for shear stress (0.213 ksi) at this point is within the range of allowable values.

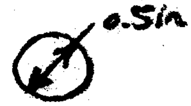
Point BC (webbed L-bracket) – As a result of the weight of the PVC extrusion pulling down on the Z-bracket and member B, the webbed L-bracket would undergo a shearing stress in the area where member B and member C are attached. The shear stress in this region (0.043 ksi) falls with the acceptable range.

Point P (Z-bracket) – the weight from the extrusion pulling down on the Z-bracket introduces a shearing stress at the edge of the Z-bracket. The shearing force would act on the thickness of the bracket. The value for shear stress (0.142 ksi) is within the acceptable range of values.

HOIST RING BOLT/U-BRACKET



SHEAR IN BOLT



$A_{BOLT} = \pi(0.5/2)^2$

$= 0.196 \text{ in}^2$

$V = \frac{F}{A}$

$= \frac{173.1 \text{ lbs}}{0.196 \text{ in}^2} = 0.882 \text{ ksi}$

$F_y = 1/3\,(24 \text{ ksi}) = 8 \text{ ksi}$

$0.882 \text{ ksi} < 8 \text{ ksi}$

OK

SHEAR IN BRACKET

$A = td$

$= (0.125 \text{ in})(0.5 \text{ in})$

$= 0.0625 \text{ in}^2$

$V = \frac{F}{A}$

$= \frac{173.1 \text{ lbs}}{0.0625 \text{ in}^2}$

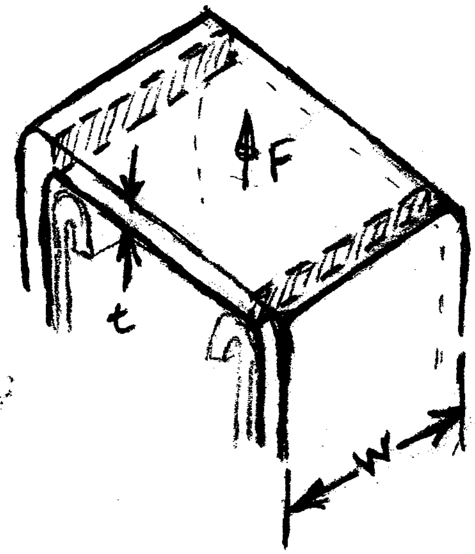
$V = 2.77 \text{ psi}$

$F_y = \frac{1}{3}(21 \text{ ksi})$

$= 7 \text{ ksi}$

$2.77 \text{ ksi} < 7 \text{ ksi}$ OK

U-BRACKET @ A/C



$A = 2wt$

$= 2(1.625\ in)(0.125\ in)$

$= 0.406\ in^2$

$V = \frac{F}{A}$

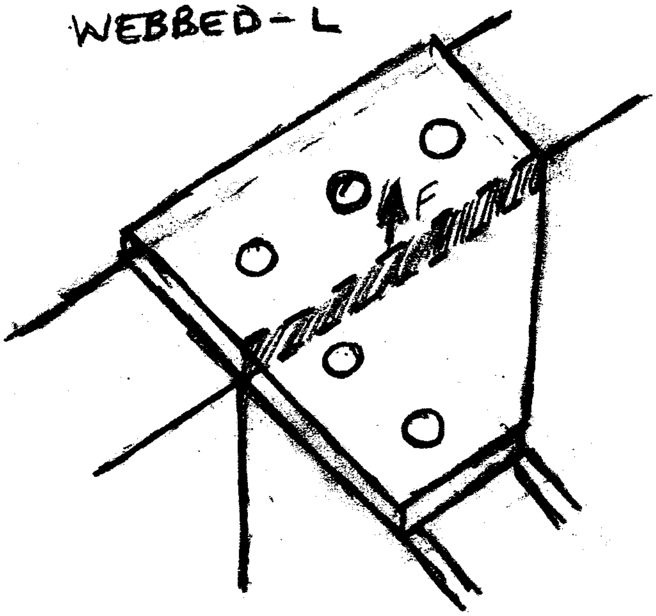
$= \frac{86.55\ lbs}{0.406\ in^2}$

$= 213.0\ psi = 0.213\ ksi$

$0.213\ ksi < 7\ ksi$

OK

WEBBED-L



$A = wt$

$= (5.375\ in)(0.25\ in)$

$= 1.34\ in^2$

$V = \frac{F}{A}$

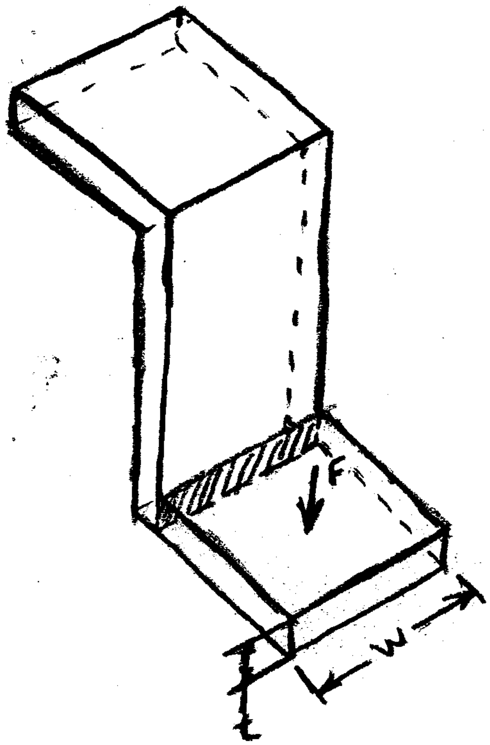
$= \frac{57.7\ lbs}{1.34\ in^2}$

$= 0.043\ ksi$

$0.043\ ksi < 7\ ksi$

OK

Z - BRACKET



$A = tw$

$= (0.25\ in)(1.625\ in)$

$= 0.406\ in^2$

$V = \frac{F}{A}$

$= \frac{57.7\ lbs}{0.406\ in^2}$

$V = 0.142\ ksi$

$0.142\ ksi < 7\ ksi$

OK